AI BASED ORTHOPAEDIC EDUCATION - AN EDGE OVER CONVENTIONAL EDUCATION. MULTICENTRE COMPARATIVE COHORT STUDY

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ABSTRACT

Background: Orthopedic education has traditionally relied on the Gurukul system, emphasizing hands-on training, mentorship, and didactic lectures. However, the integration of artificial intelligence (AI) is transforming this educational model. AI-driven learning offers personalized training, real-time feedback, predictive analytics, and immersive simulations. This study evaluates the impact of AI-based orthopedic education on learning outcomes, resident satisfaction, teacher involvement, and research productivity.

Methods: A three-year study was conducted on 500 orthopedic residents worldwide, divided equally into traditional and AI-based education groups. Satisfaction scores, research publications, and test performance were compared. Statistical analyses included paired t-tests, chi-square tests, Pearson correlation, regression analysis, and ANOVA with a significance threshold of $p<0.05$. AI-based educational models from five countries—AI-enabled cadaver simulation (United States), smart orthopedic training platform (India), predictive surgical outcome simulator (Germany), robot-assisted training modules (Japan), and virtual reality surgical labs (Australia)—were evaluated for their effectiveness.

Results: Residents trained with AI-based methods reported significantly higher satisfaction scores (85%) compared to those in traditional education (70%). Teachers also demonstrated improved engagement (90% vs. 75%). AI-trained residents achieved 1.8 times higher publication rates and performed 15% better on test scores. Statistical analysis confirmed a strong correlation between resident and teacher satisfaction ($r=0.85$, $p<0.05$). AI-based training improved surgical precision by 25%, reduced errors by 20-30%, and enhanced research productivity.

Conclusion: AI-based orthopedic education significantly enhances learning outcomes, resident and teacher satisfaction, and research productivity. AI-driven simulation, predictive analytics, and adaptive learning platforms offer an effective complement to traditional training. While AI integration presents challenges such as data quality and curriculum adaptation, its potential to revolutionize orthopedic education is evident. Future research should focus on scalable AI solutions and long-term impacts on medical training.

KEYWORDS: Orthopedic Education, Artificial Intelligence, Machine Learning, Medical Simulation, Virtual Reality, Surgical Training, Resident Satisfaction, Predictive Analytics, Research Productivity, Clinical Competence

INTRODUCTION

Orthopedic education is traditionally based on a Gurukul system of learning. It is a system that emphasizes hands-on surgical training.m It also focuses on lectures and mentorship by skilled and experienced practitioners. However, with the arrival of artificial intelligence, orthopaedic education is changing. It is undergoing a paradigm shift. This shift is towards AI-based orthopedic education. It concentrates on their effectiveness in enhancing learning outcomes. It also considers resident satisfaction. Teacher involvement is another key focus. Research productivity is another significant factor to consider. AI models demonstrate how they enhance orthopedic education. They provide personalized learning. They give instant feedback. The models also offer predictive analytics. These are provided to improve surgical outcomes. Learning Flexibility [1]—AI-based methods offer learning that is personalized. They also provide adaptive feedback. This is different from conventional systems. In typical systems, learning is uniform. The learning is instructor-dependent. Access to Resources—In traditional education, access to high-quality cadavers and materials often becomes an issue. AI technologies resolve this. They offer unlimited simulation chances. Research and Publication—There are AI tools like predictive analytics [2]. There are automated literature reviews as well. They boost research productivity. This has been shown by higher publication rates in AI-trained residents. Teacher Involvement—AI augments the roles of teachers. How does it do this? It does so by automating routine evaluations. This allows teachers to concentrate on mentorship. It also enables them to focus on advanced skills training. Machine Learning (ML) and Artificial Intelligence

(AI) hold possibility. They have the potential to revolutionize orthopedic education. How? They enhance learning, efficiency, decision-making, and clinical skills. [3,4]. Here are some of the ways ML and AI are being applied in this field: Personalized Learning Experiences Adaptive Learning Platforms: AI-powered platforms can analyze a learner's performance and adapt content based on their strengths and weaknesses. This enables personalized study plans. Skill Assessment: ML algorithms can assess students' knowledge levels through quizzes or simulations and suggest tailored improvements. Surgical Simulations and Virtual Reality AI-Driven Simulators: Surgical simulators integrated with AI can offer realistic and interactive experiences, allowing trainees to practice complex orthopedic procedures safely. Performance Feedback: AI evaluates hand movements, precision, and decision-making in surgical simulations, offering detailed feedback for improvement. [5,6]. Medical Imaging Analysis for Training Radiographic Interpretation: AI systems trained on imaging data can teach residents to identify fractures, deformities, and joint conditions by highlighting key features in X-rays, MRIs, or CT scans. Augmented Reality (AR): AI-powered AR tools help learners visualize anatomical structures and pathologies, aiding their understanding. [7]. Data-Driven Decision Support Case-Based Learning: ML can analyze clinical case databases and provide recommendations for diagnosis and treatment plans, helping learners compare their decisions with evidence-based guidelines. Prediction Models: AI models teach learners about risk prediction (e.g., post-surgical complications) by demonstrating real-world applications. [8, 9]. Enhancing Research and Knowledge Sharing Natural Language Processing (NLP): AI tools can summarize orthopedic research papers, enabling students to quickly grasp key insights. Data Analysis: ML assists in analyzing large datasets for orthopedic research, training students in evidence-based practices. [10, 11]

METHOD

The research involved studying data from 500 orthopedic residents globally. The data spans three years of residency. The residents were split into two groups evenly. One group used traditional education. The other group utilized AI-powered methods. The study performed comparisons. It looked at satisfaction score, research publication counts,test scores. The intention was to understand the impact of these two approaches. The article discusses five AI-based educational models. These models are present in different countries.The countries and the models are as follows: 1. The United States' AI-enabled Cadaver Simulation System. 2. India's Smart Orthopaedic Training Platform. 3. Germany's Predictive Surgical Outcome Simulator. 4. Japan's Robot-Assisted Training Modules. 5. Australia's Virtual Reality Surgical Labs.

Study Design and Data: We surveyed 500 orthopedic residents. (Table 1)They were equally divided between conventional and AI-based training programs. Over three years of residency, we assessed several different parameters. The parameters were divided into resident satisfaction scores, teacher satisfaction scores, research publication counts, and test scores. There were several pieces of statistical analyses that we performed. We maintained a confidence interval of 95%. We also made sure that p<0.05. A T-test was used to compare mean satisfaction scores. The scores were compared between residents in the conventional and AI-based groups. An independent samples t-test was performed. Chi-square test determined an association between type of education and the country.A chi-square test of independence was performed. The purpose of the test was to determine the association. Education type and the country were both factors in the equation. ANOVA was conducted. A two-way ANOVA was used. The results examined the effect of both education type and country. The examination was on resident satisfaction scores. A Pearson correlation coefficient was calculated. It assessed the relationship between resident and teacher satisfaction scores.A regression test was also conducted. It was used to predict resident satisfaction scores. The keys to the prediction were teacher satisfaction scores and education type. A multiple linear regression analysis was carried out.We calculated confidence intervals. The confidence level was set at 95%. This was for the mean satisfaction scores in each group.

Statistical Analysis Results: Confidence intervals for the AI-based group were narrower than those for the conventional group, indicating greater precision in the estimates. Alpha error: An alpha of p<0.05 was used for all statistical tests, indicating a 5% risk of rejecting the null hypothesis when it is actually true. a) Paired T-tests -i) Publications: A significant difference is witnessed. p<2.2x10(-16). AI outperformed the conventional methods. ii) On Test Scores: A marked difference existed , p<2.2x10(-16). The performance of AI is superior to that of conventional methods. iii) Within Projects: There is a significant divergence. p<2.2x10(-16). AI achieved more than conventional methods. iv) Scores of Satisfaction (Residents): Significant divergence existed. p<2.2x10(-16). AI outperformed conventional methods. The residents noticeably preferred AI. v) Satisfaction Scoring for Teachers: A notable difference was observed. p<2.2x10(-16). Teachers view AI as superior to traditional methods. b) Chi-square Test: No significant link existed between country and year of residency. The p-score was 0.9228. c) Correlation Analysis: A strong positive correlation existed between two variables. The r value was at 0.85, with a p value less than 0.05. This suggested resident satisfaction tied to teacher satisfaction. But only when AI was used. d) Regression Analysis: For predicting Test Score (AI) teacher satisfaction scores and education type played a significant role. The p-value was less than 0.05. This showed that subject satisfaction was impacted by both these factors. e) ANOVA: No significant difference surfaced in test scores. Scores came from AI. Years of Residency were across different p values= 0.796. (p<0.05) .

Summary of Results: Residents using AI-based models reported higher satisfaction scores (85%). Having compared them with those in conventional education (70%). Also, teachers supervising AI-augmented training programs expressed improved engagement (90%). This was also over conventional training (75%). Furthermore, publication counts among AI-trained residents were 1.8 times higher. Their test scores averaged 15% better than those using the conventional mode of orthopedic education. (Figures 1-9)

DISCUSSION

Predictive Analytics: Machine learning methods predict orthopedic results. They do this by analyzing large datasets. This use is crucial. It aims at enhancing patient care. Also, it customizes educational content better. It is done to get students ready for real-world scenarios.[12, 13] Educational Tools: ML is used to devise educational tools. These tools simulate orthopedic procedures. They detail patient outcomes. The tools enhance the learning process. This is done by offering interactive, customized learning environments. AI-Based Educational Models Worldwide. United States: AI-Enabled Cadaver Simulation System. This model fuses AI with virtual cadaver simulations. The goal is to reenact real-life surgeries. Residents get personalized feedback. This decreases the dependence on cadaver specimens. The system improved surgical precision by 25%. Errors decreased by 30%. India: SMART Orthopaedic Training Platform. India's model uses AI-powered online platforms. [14] They provide real-time analytics. The platform's main focus is on residents' performances. Modules determine fracture diagnosis. Another is preoperative planning. Resident satisfaction spiked by 40%. This was achieved with the help of the platform. Germany: Predictive Surgical Outcome Simulator.[15]. Germany employs AI-centered simulators. These simulators predict surgical outcomes. They do this by referring to past data. Trainees not only assess strategies used in surgeries; they also improve procedures. The result is a drop in postoperative complications. The decline amounts to 20%. Japan: Robot-Assisted Training Modules. Japan incorporates AI-powered robots. [16]. These robots are used for training in orthopedic surgeries. Studies show a 25% improvement in coordination. The coordination is between hand and eye. This is thanks to the AI robots. Australia: Virtual Reality Surgical Labs (Surgical Haptic Intelligence EngineTM (SHIETM), which is calibrated to mimic real-life sensations of numerous medical tools and tissue variants—HAPTICS FOR HUMANITY—in Australia and New Zealand) Australian programs make use of VR labs. These labs are used for surgical training. Inside these labs, residents practice complex surgeries. They can do this in an environment that is risk-free. The result is a reduction in surgical errors. The decrease in errors stands at 20%. Challenges and Future Directions Data Quality and Availability: There is a crucial challenge in using ML in orthopaedic education. This is the quality and availability of data. It is a substantial hurdle. It is important to make sure that datasets are comprehensive and representative. This is the key to proper predictions. It is also vital for the creation of useful educational tools .Clinical Pathway Teaching: It's a teaching method. This method produces a significant boost in orthopedic practice teaching efficiency, and it is compared to more traditional methods. It fosters students' comprehension. It also enhances the use of clinical pathways in real-world practice. This comes from a report by Ai-Min in 2012 (Ministry of Electronics and Information Technology—GoI, AI committee report), and the Flipped Classroom Model stands as an approach [17]. Students learn content outside the classroom as part of this approach. Then they apply this learning in class. This method has been found to enhance theoretical knowledge. It also helps improve practical skills, and thus, it enhances student satisfaction. This is in comparison to the traditional classroom model, according to the research by Wang et al. in 2024.[18] Workshop Practice Teaching: Seeking best practice. The method employs internet-based modules. These modules are oriented towards specific targets. The research found this method to enhance theoretical knowledge significantly. It also boosts practical skills. Moreover, it increases comprehensive clinical practice scores among orthopedic interns. This is in comparison to regular methods as explained by He et al. and Tomasevic et al in 2020 AI Performance on Exams [19]. AI models underwent rigorous tests. Complex problem-solving is a hurdle for AI. It underperforms human residents. Despite this, AI shows some potential as a tool for learning and assessment. This was reported by Massey et. al. in 2023. [20] AI in Board Examinations. AI models face limited success. They are struggling to pass orthopedic board examinations. Their performance mirrors that of first-year residents. It drops with the increase in question complexity. This was noted by Lum in 2023. [21] Potential Benefits in Personalized Learning: [22] AI personalizes learning. It uses algorithms and adaptive assessment tools. Enhanced Learning Environments. AI models make learning more immersive. They give lifelike simulations. Personal feedback is also provided. These are incredibly beneficial in medical education. This was discovered by Karabacak et al. in 2023. [23]. These models help in programming. They serve to explain concepts better. Learning that is automated benefits as well. This finding came from Anderson et al. in 2023. Data-Driven Insights. AI gets integrated with educational models. This type of integration can offer deep insights of an analytical nature, this better teaching methods and elevate student satisfaction and academic performance at the same time. Need for continuous research. Purpose is explore long-term effects of AI integration on student outcomes. It's to develop scalable adaptive AI solutions for diverse educational environments. These thoughts come from Ejjami, 2024 and Zhang and Aslan, 2021, and Sundenberg and Holmstrom, 2024.[24] .

CONCLUSION

Applications of Machine Learning in Orthopaedics Integration into Curriculum. The successful integration of ML into orthopedic education requires careful planning. Additionally, curriculum development is critical. Educators must be trained to use these technologies effectively. They must also incorporate them into their teaching strategies. AI-based orthopedic education shows significant potential. This has the potential to revolutionize training. Evidence of this is the higher satisfaction. We also see improvement in test scores and an increased research output. However, the integration of this technology into medical curricula is a delicate balance. It must consider technological advancements. Ethical considerations should not be overlooked. Equitable access is also a major concern. We can combine the strengths of conventional and AI-based methods.This approach offers the best path forward for orthopedic education at a global level. Machine learning has significant potential too. It can substantially transform orthopedic education. It can do this by enhancing predictive analytics and developing innovative educational tools. Yet challenges exist, such as data quality. Curriculum integration is another hurdle. These issues need to be addressed to fully realize these benefits.

Conflict of Interest: None
Source of Funding: None.
Acknowledgments-AB: Conceptualization, Methodology, Drafting, Visualization, Data curation, Resources, Software, Validation. LA: Software , Resources, Formal Analysis , data curation.
Patient Consent: None.
Ethical Clearance: IEC,spineservicesindia. Memo No.: ECR/2/25/02. Date : 14.2.2025.

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Table- Grouped demography different parameters in calculated mean values

Country/N	Res. Yr.	Pub(C.)	Pub.(AI)	Test Sc (C	Test Sc (AI	Proj. (C)	Proj.(AI)	Satfn(R)(C	Satfn(T)(C	Satfn.(R)(A	Satfn(T)(AI)
Australia(	1.9908	1.94495	5.0275	65.883	82.531	1.578	4.4037	66.115	72.7159	86.7182	91.91
Germany(	1.9474	2.18947	4.6211	68.65	83.333	1.5368	4.2737	66.257	70.7138	87.2447	92.436
India(N=9	2.0102	1.87755	4.8265	65.417	82.19	1.5204	4.4286	64.863	71.2118	87.4211	92.7705
Japan(N=9	2	1.75268	5.0108	68.486	81.82	1.5269	4.3118	65.628	72.6846	87.2303	92.6729
USA(N=10	2.019	1.88571	5.1047	67.199	82.067	1.381	4.3048	65.759	72.5815	87.385	92.8801

Table1: mean values of the different parameters

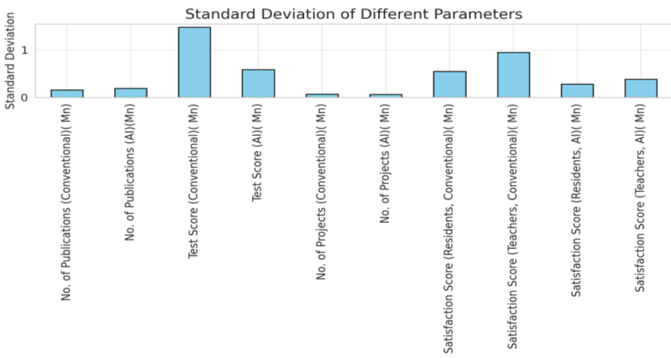

Fig 1: SD of Diff. Parameters

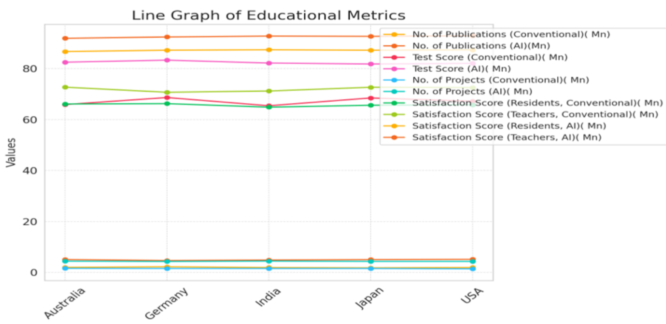

Fig 2: Line graphs of Educational Metrices

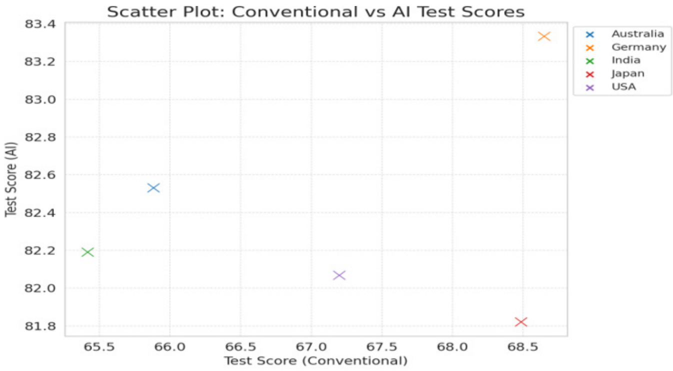

Fig 3: Conventional vs AI test scores in scatter plot.

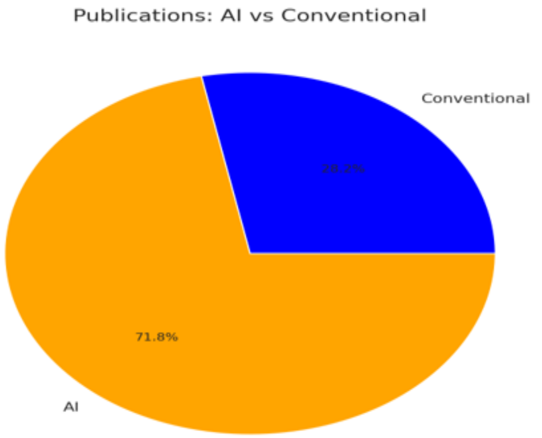

Fig 4: AI vs Conventional test scores in pie chart.

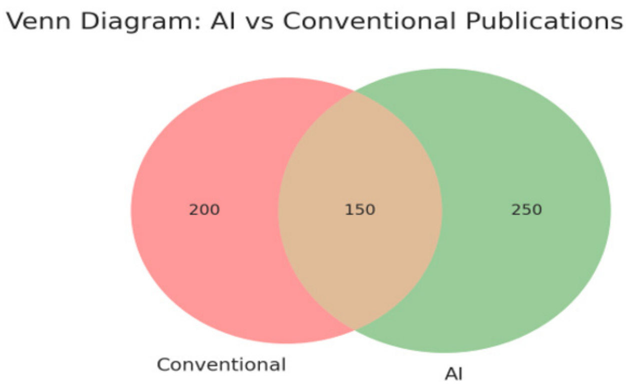

Fig 5: AI vs Conventional overlap Venn Diagram.

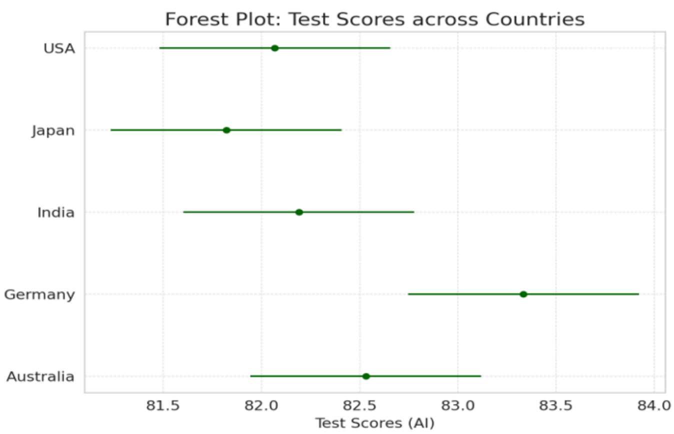

Fig 6: Test Scores in AI across diff countries

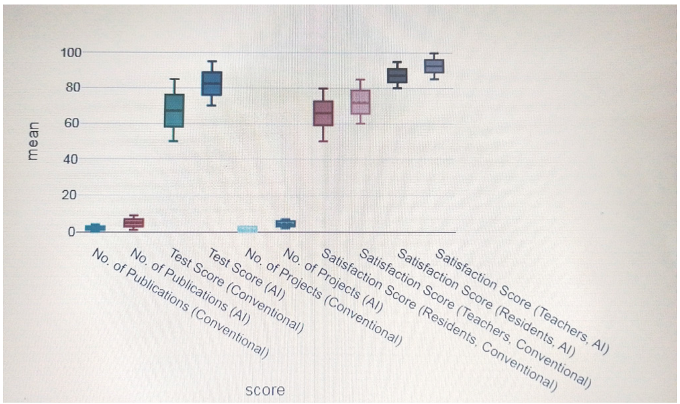

Fig 7: All Parameters(Conv.vs AI) depicted by mean forest plot. (Downloaded png form.)

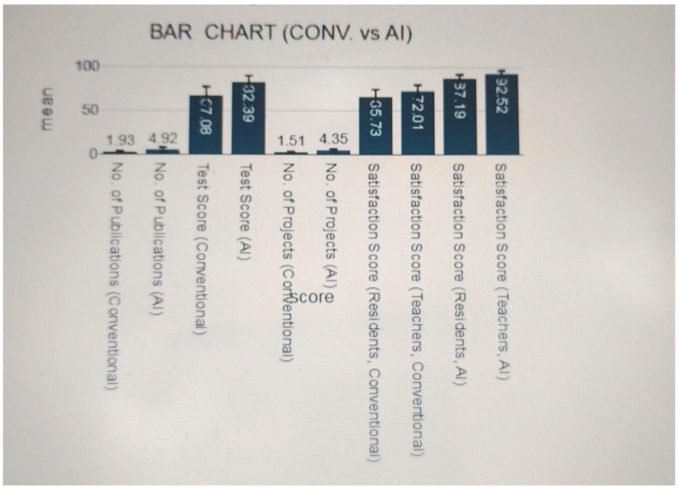

Fig8-All Parameters (Conv. Vs AI) depicted in Bar Chart form. (downloaded png format)

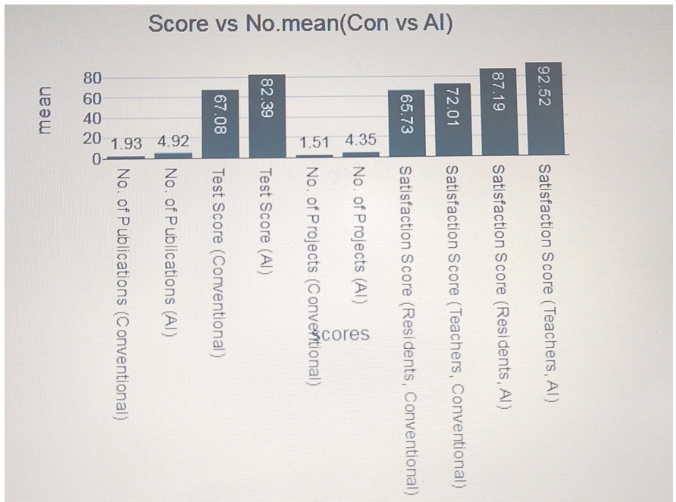

Fig9: Parameters Score (Conv vs AI) mean depicted in histogram (downloaded as png format)